

# Design and Analysis of an Axisymmetric Phased Array Fed Gregorian Reflector System for Limited Scanning

Alan J. Fenn and Jared W. Jordan

Lincoln Laboratory, Massachusetts Institute of Technology, Lexington, MA 02420-9185, USA

[ajf@ll.mit.edu](mailto:ajf@ll.mit.edu)

**<sup>1</sup>Abstract**— An axisymmetric phased array fed confocal parabolic Gregorian reflector system is explored. The antenna utilizes a planar phased array located near the vertex of the primary reflector. Numerical electromagnetic simulations based on the multilevel fast multipole method (MLFMM) were used to analyze and optimize the antenna parameters for limited scanning. Simulations of the scanning performance of a dual reflector system with a 2 meter diameter primary reflector operating at Ku band are presented.

## 1. INTRODUCTION

Reflector antennas with limited electronic scanning are of interest for communications and radar applications. For space applications, attitude control systems can provide good angular control of the antenna aperture with small residual angular errors on the order of  $\pm 0.5^\circ$  or less in the antenna main beam pointing direction. To reduce residual angle errors due to limitations in mechanical pointing, electronic compensation of beam pointing can be considered. A well-known approach to generating limited electronically scanned beam radiation patterns is to utilize a Gregorian dual-reflector antenna system with confocal paraboloids and a phased array feed. This type of antenna system is usually designed in an offset configuration to avoid blockage effects [1-4]. However, in this study, an axisymmetric Gregorian antenna system design was desired, which could allow easier fabrication compared to an offset design. In the case of a space-deployable antenna [5-8], a reduction in mass and maintaining surface tolerances are important goals, which might be achieved using an axisymmetric inflatable design as depicted as an artist's concept in Figure 1. Thin-film materials with and without electrically conducting coatings can be considered for designing a space-deployable antenna. The phased array feed is assumed to be an ideal planar source in this study. In the case where a large magnification is used with limited scanning, the diameter and subsequently the blockage of the subreflector can be relatively small. A 2m diameter Ku-band Gregorian reflector system operating at 16 GHz ( $\lambda=1.875$  cm) with half-power beamwidth  $0.56^\circ$  and limited main beam scanning has been analyzed and optimized using

numerical simulations with the multilevel fast multipole method (MLFMM). Section 2 describes the electromagnetic simulation model. Section 3 presents simulated results and Section 4 has a summary.

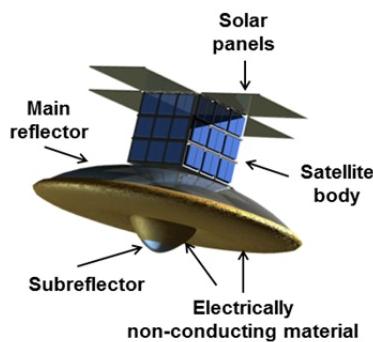


Figure 1. Artist's concept of an inflatable axisymmetric Gregorian reflector system deployed from a generic satellite body.

## 2. ANTENNA NUMERICAL SIMULATION MODEL

As shown in Figure 2, a Ku-band Gregorian confocal reflector system with a primary parabolic reflector diameter  $D=2\text{m}$  and focal distance  $f_p=0.8\text{m}$  ( $f_p/D=0.4$ ), parabolic subreflector diameter  $d=0.5\text{ m}$  and focal distance  $f_s=0.12\text{m}$  ( $f_s/d=0.24$ ), and phased array diameter  $0.2\text{m}$ , has been analyzed and optimized using numerical simulations conducted with the multilevel fast multipole method (MLFMM) using FEKO software ([www.feko.info](http://www.feko.info)). The primary and secondary reflectors were analyzed as perfect electric conductors. Optimization was performed as a grid search with the subreflector diameter and subreflector focal distance taken as the search parameters. The search optimization goal was assumed here to be peak directivity for a  $0.5^\circ$  scan angle. The magnification factor for this reflector system is given by the ratio of the primary to subreflector focal distances or  $m = f_p/f_s = 6.67$ . The angle from the center of the feed array to the edge of the subreflector is  $18^\circ$ .

<sup>1</sup> Distribution A: Public Release; unlimited distribution. This work is sponsored by the Department of the Air Force under Air Force Contract #FA8721-05-C-0002. Opinions, interpretations, conclusions and recommendations are those of the authors and are not necessarily endorsed by the United States Government.

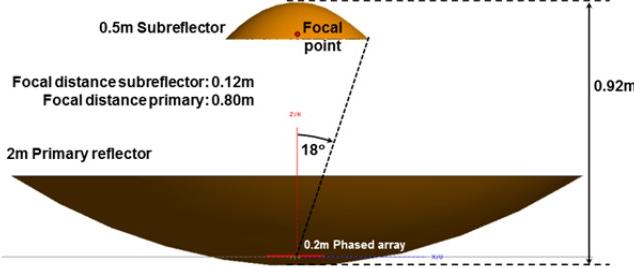


Figure 2. Side view of an example Ku-band axisymmetric Gregorian reflector system with planar phased array feeding confocal paraboloids.

Assuming a maximum scan angle for the feed array of  $10^\circ$ , to avoid grating lobes the maximum element spacing is  $0.85\lambda$ . In this study, the phased array feed is an ideal 20 cm diameter circular aperture source with linearly polarized elements spaced  $0.8\lambda$  on a square grid as depicted in Figure 3. The effects of array mutual coupling is ignored in the simulation model. The feed array half-power beamwidth is  $5.6^\circ$  at 16 GHz, so the subreflector will be efficiently illuminated even at the maximum array scan angle.

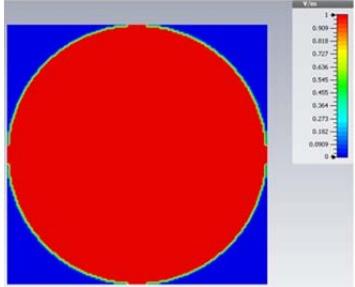


Figure 3. Phased array feed simulation model with ideal linearly polarized uniform amplitude illumination over a 20 cm diameter circular aperture with element spacing 1.5 cm on a square lattice.

### 3. RESULTS

The main beam of the reflector system was scanned by providing a progressive linear phasing across the feed array such that the feed array main beam scanned to up to  $10^\circ$  from the array boresight. Figure 4 shows the surface currents in dBA/m on the primary and secondary reflectors as the array main beam is scanned at  $0^\circ$ ,  $-5^\circ$  and  $-10^\circ$  in the H-plane. In each case, the primary reflector is, in part, under illuminated, which will result in reduced directivity compared to a fully illuminated reflector. Direct illumination of the primary reflector from the near-field sidelobes of the phased array feed is observed, and this illumination will result in some degradation in the Gregorian antenna directivity. Spillover at the primary reflector is observed at the  $-5^\circ$  and  $-10^\circ$  array scan angles, which results in reduced directivity. For a 2 meter diameter primary reflector with a typical 60% efficiency, the peak directivity at 16 GHz is on the order of 48.3 dBi.

Simulated directivity patterns for the axisymmetric Gregorian reflector system with phased array feed scanned in the H-Plane from  $0^\circ$  to  $-9^\circ$ , which generates main beam limited scanning from  $0^\circ$  to  $1^\circ$  are shown in Figure 5. Due to the grid search optimization simulations, the peak directivity occurs at  $0.5^\circ$  for the case where the array scan angle is  $-4^\circ$ . A display of the main beams and wide-angle sidelobes for the cases where the array scan angles are  $0^\circ$  and  $-4^\circ$  is shown in Figure 6. The peak directivity for the Gregorian antenna broadside scan is 44 dBi and increases by 2 dB to 46 dBi for the Gregorian  $0.5^\circ$  scan as observed in the expanded scale plot in Figure 7. It is further evident from Figure 7 that the directivity at an observation angle of  $0.5^\circ$  improves by 8.5 dB (increases from 37.5 dBi to 46 dBi) when the array scans from  $0^\circ$  to  $4^\circ$ . The maximum directivity based on area for a 2m aperture at 16 GHz is 50.5 dBi, so 46 dBi indicates an aperture efficiency of  $-4.5$  dB (36% efficiency). Similar results, not shown here, are obtained for array scanning in the E-plane.

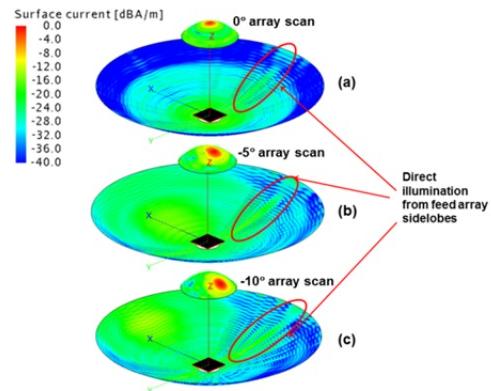


Figure 4. Simulated surface currents for the axisymmetric Gregorian reflector system with phased array feed scanned in the H-Plane. (a)  $0^\circ$  array scan, (b)  $-5^\circ$  array scan, and (c)  $-10^\circ$  array scan.

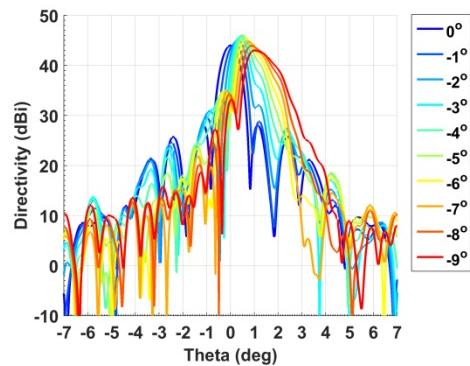


Figure 5. Simulated directivity patterns for the axisymmetric Gregorian reflector system with the phased array feed scanned in the H-Plane from  $0^\circ$  to  $-9^\circ$ , which generates main beam limited scanning from  $0^\circ$  to  $1^\circ$ .

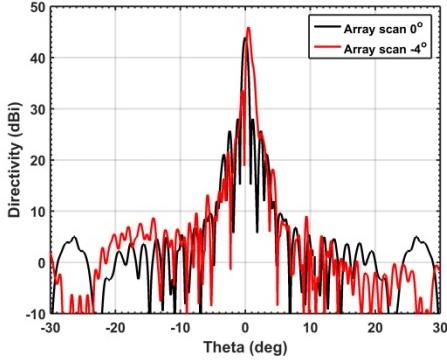


Figure 6. Simulated directivity patterns over a  $60^\circ$  field of view for the axisymmetric Gregorian reflector system with the phased array feed scanned in the H-plane at  $0^\circ$  and  $-4^\circ$ , which generates main beam scanning at  $0^\circ$  and  $0.5^\circ$ .

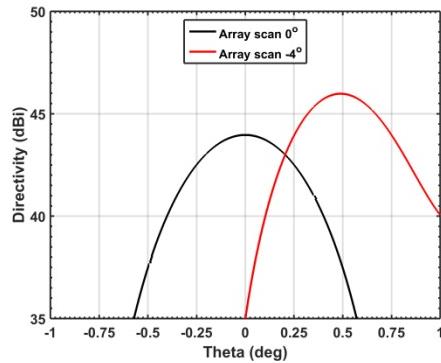


Figure 7. Expanded view of simulated directivity patterns over a  $2^\circ$  field of view for the axisymmetric Gregorian reflector system with phased array feed scanned in the H-plane at  $0^\circ$  and  $-4^\circ$ , which generates main beam scanning at  $0^\circ$  and  $0.5^\circ$ .

## 5. SUMMARY

The design of an axisymmetric phased array fed confocal parabolic Gregorian reflector system has been explored. The antenna utilizes a planar phased array located near the vertex of the primary reflector. Numerical electromagnetic simulations based on the multilevel fast multipole method were used to analyze and optimize the antenna parameters for limited scanning. Simulations of the scanning performance of a dual reflector system with a 2 meter diameter primary reflector operating at 16 GHz were presented. In this design, a grid search optimization procedure was used to design the subreflector diameter and focal distance for  $0.5^\circ$  scan angle. The grid search approach could be applied to achieving wider scan angles with this antenna type. Future studies should include the effects of reflector surface errors and errors due to phase and amplitude illumination of the phased array feed. In the case where reflector surface errors or reflector alignment is

present, phased array calibration and compensation could be used to improve performance

## ACKNOWLEDGMENT

Technical discussions with Jason R. Franz, Pamela R. Evans, Frank C. Robey, H. David Goldfein, Robert G. Atkins, Jeffrey S. Herd, Jesse H. Mills, and Dennis A. Burianek, are sincerely appreciated. Casey Reed provided graphic art support.

## REFERENCES

- [1] C.J. Wilson, Electronically Steerable Field Reflector Techniques, Technical Report No. RADC-TR-64-521, Feb. 1965.
- [2] W.D. Fitzgerald, Limited Electronic Scanning with an Offset-Feed Near-Field Gregorian System, MIT Lincoln Laboratory Technical Report 486, 24 Sept. 1971.
- [3] J.A. Martinez-Lorenzo, A. Garcia-Pino, B. Gonzalez-Valdes, and C.M. Rappaport, Zooming and Scanning Gregorian Confocal Dual Reflector Antennas, IEEE Trans. on Antennas and Propagat., vol. 56, no. 9, 2008, pp. 2910-2919.
- [4] A.J. Fenn and R.J. Richardson, Analysis of an Adaptive Two-Reflector Phased-Array Fed System, 1980 IEEE Antennas and Propagation Society International Symposium Digest, 2-6 June 1980, pp. 134-137.
- [5] R.E. Freeland, G.D. Bilyeu, and G.R. Veal, Development of Flight Hardware for a Large Inflatable-Deployable Antenna Experiment, Acta Astronautica, Vol. 38, Nos. 4-8, pp. 251-260, 1996.
- [6] Y. Xu and F. Guan, Structure Design and Mechanical Measurement of Inflatable Antenna, Acta Astronautica, Vol. 76, pp. 13-25, 2012.
- [7] A. Babuscia, M. Van de Loo, Q. J. Wei, S. Pan, S. Mohan, and S. Seager, Inflatable Antenna for CubeSat: Fabrication, Deployment and Results of Experimental Tests, 2014 IEEE Aerospace Conference, pp. 1-12.
- [8] A. Babuscia, T. Choi, C. Lee, and K-M. Cheung, Inflatable Antennas and Arrays for Interplanetary Communication using CubeSats and SmallSats, 2015 IEEE Aerospace Conference, pp. 1-9.

